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Electromagnetic Locking System for a Safety Switch

The present invention relates to a locking system for a safety switch having an actuator, as specified in the preamble of claim 1.

Safety switches with a read head and an actuator, each having a first and/or second component set with electric and/or electronic structural elements which may be caused to interact without electric contact and as a result control the safety switch, have been disclosed in DE 197 11 588 A1, for example. Safety switches such as these may be used to monitor movable protective devices such as doors, covers, grates, and the like of machinery and equipment. As a rule the safety switch interrupts one or more electric circuits when the relevant protective device is transferred to a safer operating state, is switched off, for example, or switching on of the device is prevented.

The actuator generally is introduced in a channel formed by the read head. When assembled, the actuator in the read head may be mechanically locked and as a result the

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protective device may be kept locked. Locking in the state of the art is accomplished as a result of extension of a rod directly through an opening in the actuator or blocking of a control gear in the read head operating in conjunction with the actuator. In order for it to be possible to apply the locking forces required, 1000 N, for example, as a function of the application the locking system and accordingly the safety switch must be designed to be sufficiently rugged from the mechanical viewpoint.

As an alternative or in addition to the mechanical locking the locking may be effected by electromagnetic forces, which are, of course, heavily dependent on the distance between the electromagnet and the associated counterelement, and in particular decrease sharply with increase in distance. The fouling of the safety switch and of the locking system which occurs may impair provision of high locking forces and other aspects of operation in fouling environments such as in the vicinity of metal-cutting machine tools.

DE 199 53 898 A1 discloses an access protection device having a U-shaped holding magnet. A configuration having a rotatable U-shaped permanent magnet is described for the exemplary embodiment, a configuration such that a first reed contact detects the rotary position of the permanent magnet, that is, engagement or disengagement of the magnetic locking action, while a second reed contact detects the presence or absence of the counterelement, that is, whether the protective door is closed or not.

DE 198 40 620 C1 discloses a contact-free safety switch having a Hall sensor mounted on the read head and a permanent magnet mounted on the actuator. The Hall sensor monitors the closed position, the switching threshold of the Hall sensor being adjustable by means of a trimming resistor.

The object of the present invention is solution of the problem of further improvement in the locking systems of a safety switch, especially the problem of reliable monitoring of locking by electromagnetic forces.

The problem is solved by the locking system specified in claim 1. Particular forms of configuration are specified in the dependent claims.

In the case of a locking system of a safety switch having a read head and an actuator each having a first and/or second component set with electric and/or electronic structural elements which may be alternately engaged and disengaged without the use of electric contacts so that the safety switch may be controlled, the problem is solved in that the actuator on the read head may be locked by means of a switchable electromagnet operating in conjunction with a counterelement, and in that the locking may be controlled by means of a sensor element the output signal of which depends on the magnetic field which may be generated by the electromagnet.

None of the state-of-the-art publications disclose a sensor element which provides an analog output signal by which the intensity of the magnetic field of an electromagnet and accordingly the locking force generated may be monitored. In use of an electromagnet as claimed for the invention this locking force is adjustable, and continuously adjustable by means of suitable electric actuation. In contrast, only one switching state or one position is determined discretely and digitally by the known sensor elements in the state of the art so as to establish whether the permanent magnet has been rotated to the locking position or whether the protective door is closed. The adjustability of the locking force also permits automatic association, in particular under program control, of different operating conditions of the machine to be monitored with different locking forces for the respective protective mechanism.

Electric contact-free interaction of read head and actuator may be effected with all known processes of the state of the art, in the simplest case by damping of electromagnetic waves, especially those of an electromagnetic field. As an alternative, use may be made of a so-called transponder system in which identification signals are exchanged electrically, free of contact, between read head and actuator. In the state of the art the three-dimensional area of response of the interactive system is used only to a limited extent and a relatively precise orientation of read head and actuator toward each other in the assembled state is required.

The locking is not effected at all or at any rate is not effected exclusively by a bar which may be moved transversely to the direction of movement of the actuator, but rather by the action of an electromagnetic force on the counterelement. The electromagnet may be switched by the safety switch itself and/or an associated control mechanism and/or the machine associated with the safety switch. The level of the locking force may be adjusted, for example, as a function of the operating state of the associated machine. By preference the counterelement and/or the electromagnet is mounted so as to be pivotable relative to the base element. During locking the electromagnet and the actuator are positioned so close to each other that sufficiently high locking forces may be achieved. In addition, the first and/or second component set preferably is integrated with the respective counterelement, so that interaction of the component sets is reliably ensured even under adverse conditions, for example, even in the event of angular displacement of the protective mechanism.

In one particular embodiment the sensor element is mounted in the actuator. By preference the actuator furthermore has the base element, the counterelement, and the second component set; in particular, these elements form the actuator. As an alternative or in addition, the read head as well may have one or more sensor elements. It is conceivable, for example, that

the damping of the magnetic field generated by the electromagnet could be measured directly in the read head.

Independently of the number and configuration of the one or more sensor elements, the safety switch may be controlled by direct or indirect coupling of the output signal of the sensor and by interaction of the first and second component sets. Direct coupling is effected, for example, when the first and/or second set may be operated only if the sensor element provides a suitable output signal. Indirect coupling is effected, for example, if the output signal of the first and/or second component set is received by superordinate control electronics and the output signal of the sensor element is also received independently of this circumstance. Linking of the two output signals then occurs in the superordinate control electronics, which, for example, determines if an operating state of the machine to be monitored exists for which the output signal of the sensor element is relevant.

In one preferred embodiment of the invention the sensor element may assume two switching states as a function of the magnetic field which may be generated by the electromagnet. By preference the second component set mounted in the actuator is controlled by the switching states of the sensor element. This yields the advantage that the actuator may be developed without external electric connections. All the electric or other connections required are preferably mounted within the actuator so as to be protected from disruptive influences of a mechanical or other nature from coming from the exterior. The sensor element may also be mounted directly on or in the second component set of the actuator or may be integrated into it. It is, of course, advantageous in many applications for the sensor element of the second component set to be positioned some distance away on the actuator. By preference at least one sensor element is mounted in an edge area of the actuator in order for it to be possible to determine not just one or in any event only one axial distance from the electromagnet but also

displacement in a direction perpendicular to the direction of movement of the relative movement between electromagnet and actuator.

In one preferred embodiment of the invention a generator coil is mounted in the actuator for provision of electric energy for the second component set. This generator coil generally receives an electromagnetic signal from the first component set of the read head and from this signal generates the voltage required or the current required for operation of the electric and/or electronic components.

In one especially simple embodiment of the invention the sensor element is connected electrically in series to the generator coil. This makes it possible to switch on the power supply for the second component set in the actuator only if the sensor element detects a sufficiently high or sufficiently low magnetic field generated by the electromagnet.

If several sensor elements are mounted on the actuator and/or the read head, their output signals may be interconnected as desired to monitor the locking. Three-dimensional or in any event two-dimensional distribution of the several sensor elements in keeping with the respective requirements and geometric relationships, for example, on the mounting surface of the actuator in particular, is advantageous. The relative position of the actuator in relation to the electromagnet in the locked state may also be determined in this way.

The position of one or more of the sensor elements may be adjusted by individual or collective adjustment means. The adjustment may generally be made in all three spatial directions and/or in rotary directions. In many applications, however, the possibility of adjustment in the direction of the relative movement of actuator and electromagnet or at an angle of 90° to such movement is a consideration of importance.

In one particular embodiment the sensor element has a reed contact and/or a Hall element; in particular the sensor element may be in the form of a reed contact or a Hall element. A Hall element presents the advantage over a reed contact not only that one or more switching points may be assigned but also that an analog output signal relating to the intensity of the magnetic field generated by the electromagnet may be produced.

Other advantages, features, and details of the invention are presented in the dependent claims and the following description, in which several exemplary embodiments are described in detail with reference to the drawings. The features mentioned in the claims and in the description may be essential to the invention either individually or in any combination.

- FIG. 1 presents a perspective view of a read head of a safety switch having a locking system as claimed for the invention,
- FIG. 2 a perspective view of an accompanying actuator,
- FIG. 3a a first exemplary embodiment of the second component, in which a generator coil and a transponder are mounted,
- FIG. 3b a second exemplary embodiment of the second component in which the transponder is connected directly to the generator coil,
- FIG. 4 a section through the read head and the actuator of the locking system in the assembled state,
- FIG. 5 the locking system of FIG. 4 in the modified state,

FIG. 6 a diagram of the measured locking force, and

FIG. 7 a diagram of a protective mechanism.

FIG. 1 presents a perspective view of the read head 2 of a safety switch have a locking system 1 as claimed for the invention (FIG. 4). The read head 2 is at least a part of the safety switch not shown. The electric switching function may be performed inside the head housing 4 or in a switching component of the safety switch mounted remote from the head housing 4. Electric contact of the read head 2 is effected by way of one or more plug-and-socket connectors 5. The head housing 4 is more or less square in shape, with an essentially rectangular and preferably planar front surface 6. Below its center the head housing 4 has a cylindrical boring the longitudinal axis of which forms a right angle with the front surface 6 and into which the electromagnet 7 may be introduced. In one preferred exemplary embodiment the read head 2 is secured by means of the head housing 4 on a frame of the protective device (not shown) or on the machine itself.

The electromagnet 7 has a more or less cylindrical housing which forms on its side facing the actuator 3 a more or less cylindrical and preferably planar mounting surface 8. The housing of the electromagnet 7 is in the form radial externally of an annular and preferably planar edge 9 which is separated from the first mounting surface 8 by an annular groove 28. The first mounting surface 8, the annular edge 9, and the front surface 6 preferably are positioned in one plane.

The first component set 10 is mounted so as to be stationary above the electromagnet 7 in the head housing 4, and in particular is detachably or non-detachably secured by a threaded connection of the head housing 4. The wiring between the first component set 10, the

electromagnet 7, and the connection for the plug-and-socket connector 5 preferably is mounted inside the head housing 4. A cable clip 11 for securing the connecting lines for the plug-and-socket connector 5 is mounted on a side surface on the head housing 4. The preferably planar front surface or third mounting surface 23 (FIG. 4) of the first component set 10 is aligned with the first mounting surface 8 or is offset slightly to the rear of this surface.

FIG. 2 presents a perspective view of an associated actuator 3 which has a counterelement 12, such as one of steel, by means of which the actuator 3 may be secured on the read head 2 by the electromagnet 7 and by which the protective mechanism may be locked. The counterelement 12 may be in one piece of steel or only partly so, for example, for the purpose of forming a frame of aluminum for seating an insert operating in conjunction with the electromagnet. The counterelement 12 is rigidly connected to an associated base element 13, such as one of aluminum, but is pivotable relative to this element, as is explained in the following description in connection with FIG. 4. The second component set 14, which may be made to interact with the first component set 10 of the read head 2 in the absence of electric contact, is rigidly connected to the counterelement 12, and by preference is detachably attached to it by means of fastening screws.

The counterelement 12 forms a preferably planar second mounting surface 15 which may be brought into areal contact with the first mounting surface 8 of the read head 2 during the locking process. The preferably planar front surface or fourth mounting surface 24 (FIG. 4) of the second component set 14 is aligned with the second mounting surface 15 or is slightly offset relative to this mounting surface. It is essential in the process for the configuration of the first and second component sets 10, 14 to ensure establishment of contact between the first and second mounting surfaces 8, 15 of the electromagnet 7 and respectively of the counterelement 12, since especially great locking forces may be thereby achieved.

The actuator 3 is secured, for example, on a protective mechanism by means of the base element 13 for a machine switchable by the safety switch. The counterelement 12 together with the second component set 14 may be pivoted relative to this protective device about the three spatial directions x, y, z shown in FIG. 2, each of which encloses a right angle relative to each other. The direction of spacing between the counterelement 12 and the base element 13 is represented in this instance by the spatial direction z. In the main, the counterelement 12 may not be displaced relative to the base element 13 in this direction of spacing z. Both the counterelement 12 and the base element 13 have a more or less rectangular basic shape with rounded edges. The grooved recesses 16 in the counterelement 12 serve the purpose of accessibility of the fastening means, screws in particular, which may be introduced into the fastening openings 17 in the base element 13 and may be used to secure the actuator 3 on the movable part of the protective mechanism.

In the embodiment illustrated the second component set 14 has no connecting lines, so that establishment of electric contact with the actuator 3 is not necessary. By preference energy is conducted to the second component set 14 in the actuator 3 by way of the first component set 10 mounted in the read head 2 for the purpose of reading out identification data stored in the second component set 14 and transmitting such data back to the first component set 10. In a simplified embodiment the second component set 14 may only damp, as desired, an alternating electromagnetic field generated by the first component set 10 and as a result announce to the first component set 10 and the read head 2 respectively the presence of the of the second component set 14 and accordingly the closed position of the protective mechanism.

In the exemplary embodiment illustrated a total of four sensor elements 31, 32, 33, 34 are mounted more or less centrally relative to the second mounting surface 15 and at the corners of an assumed isosceles triangle. Each of the sensor elements is embedded in or secured on a

suitable disk, circular in the exemplary embodiment, of plastic or the like. This plastic disk has as adjusting means 30 an adjustment slot by means of which the position of the associated sensor element 31 may be adjusted in the direction of the z axis. The second sensor element 32 mounted in the center may be used to determine if a relevant magnetic field is at all present in the field surrounding the actuator 3. The first, third, and fourth sensor elements 31, 33, 34 located at the corners of the assumed isosceles triangle in addition make it possible to determine the position of the actuator 3, in particular that of the counterelement 12, relative to the magnetic field which may be present. The output signals of the sensor elements 31, 32, 33, 34 preferably are connected by use of the electric and/or electronic components in the second component set 14.

FIG. 3a illustrates a first exemplary embodiment of the second component set 14, in which embodiment a generator coil 35 and a transponder 36 are mounted. A reed contact 37 mounted outside the second component set 14 in the embodiment illustrated is connected electrically in series to the generator coil 35. In the event of approach of the reed contact 37 to the vicinity of the magnetic field generated by the electromagnet 7, the contact stud 42 of the reed contact 37 is deflected in the direction of actuation 43 and as a result the transponder 36 is connected electrically to the generator coil 35. In place of a make contact use may also be made of a break contact which short-circuits when the generator coil 35 is not actuated, thereby preventing exchange of signals between the first and second component sets 10, 14.

Both the second component set 14 and the reed contact 37 are mounted on or in the actuator so that movement of the reed contact 37 and accordingly of the actuator 3 is accompanied by approach of the second component set 14 to the first component set 10 mounted in the read head 2. A suitable transmitting coil in the first component set 10 sends an electromagnetic signal which is received in the generator coil 35 and is converted at least to some extent back to electric energy. By means of this electric energy a data signal stored in the

transponder 36 is read out and transmitted back to the first component set 10 of the read head by means of the generator coil 35. However, this data signal may be read out only if the contact stud 42 has been deflected, such being the case only if the magnetic field generated by the electromagnet 7 is of an assigned strength such that, for example, locking to a sufficient extent is ensured.

FIG. 3b illustrates a second exemplary embodiment of the second component set 114 in which the transponder 136 is connected directly to the generator coil 135. Spaced a certain distance from the second component set 114 there is mounted as sensor element a Hall element 38, which is fed over the feed lines 44 from the transponder 136 and the output lines 45 of which are run back to the transponder 136 for evaluation.

FIG. 4 shows a section in the y/z plane through the read head 2 and the actuator 3 of the locking system 1 when assembled. What is to be observed in particular in the cross-section shown is the shape of the elastically deformable element 18, which is designed to be symmetrical in rotation relative to the direction of spacing z. The washer 20 is designed to be more or less cupshaped and forms a stop especially during locking and the accompanying transfer of force from the counterelement 12 by way of the connecting element 19 to the base element 13, and accordingly from the read head 2 to the actuator 3 and respectively the protective device, and/or during screwing in of the connecting element 19 and/or swiveling of the counterelement 12 relative to the base element 13. The socket 18 is in contact with both the base element 13 and the connecting element 12 and when vibrations or impacts occur damps the tendency of the counterelement 12 to oscillate, thereby preventing generation of noise or rattling such as is caused, for example, by impact of the counterelement 12 on the base element 13.

The first sensor element 31 may be screwed into a threaded opening 41 in the counterelement, against the action of an energy storing element 40, in the exemplary embodiment a helical spring. Insertion is effected preferably by engagement of a tool into the adjusting slot 30, or optionally by use of a suitable coin. Establishment of electric contact with the electric sensor element 31 is for the sake of clarity of illustration not shown in FIG. 4; it may be effected, for example, by sufficiently long connecting leads which subsequently are connected to component set 14. The threshold value which when reached by the first sensor element 31 generates an assigned output signal may be adjusted by rotation of the first sensor element 31 forward or backward. The first sensor element 31 is adjusted in the z direction only in the exemplary embodiment illustrated, but may also be adjusted in the x and y direction by means of suitable adjusting devices.

As a variation of the exemplary embodiment shown in FIG. 4 it may be advantageous to mount at least one sensor element 31, 32, 33, 34 near or on the surface of the counterelement 12 facing the base element 13, but in any event offset backward from the first mounting surface 8 of the counterelement 12. The sensor element 31, 32, 33, 34 and/or the associated adjusting means 30 in particular may be accessible from this rear side. As a result, a first mounting surface 8 of the counterelement 12 with at least some of its area closed may be provided and the sensor element 31, 32, 33, 34 and/or the associated adjusting means 30 are mounted so as to be protected.

The adjusting means 30 may be actuated, above all in the direction of the z axis, by way of openings in the base element 13 and/or in the connecting element 19. The longitudinal axis of a reed contact 37 and/or the direction of switching of the latter may extend more or less in parallel with the z axis or enclose an angle more or less of 90° with this axis.

FIG. 5 shows the locking system 1 in a state in which the actuator 3 is separated from the read head 2 by a distance d . The electromagnet 7 mounted in the read head 2 is represented by broken lines and has several turns 25. A magnetic field is induced in the coil core 26 when current is applied to the turns 25. Another Hall element 39 mounted in the coil core 26 determines the field intensity which occurs. This field intensity depends among other things on the distance d of the counterelement 12 of the actuator 3 short-circuiting the magnetic flux. In particular, the field intensity determined by the other Hall element 39 and accordingly the associated hall voltage U_{Hall} increase with decrease in distance d .

As an alternative or in addition, the first sensor element 31 in the actuator 3 may be in the form of a Hall element and measure the magnetic intensity present in the actuator 3 and respectively the associated magnetic induction, which also is a function of the distance d of the actuator 3 from the read head 2 and respectively from the electromagnet 7.

The magnetic field intensity measured by the other Hall element 39 and/or by the first sensor element 31 is a gauge of the locking force F acting between the read head 2 and the actuator 3, in the case of a rigidly mounted read head 2 acting in particular on the actuator 3 and in the direction of the read head 2. There may accordingly be assigned for the other Hall element 39 and/or the first sensor element 31 threshold values which when reached may signal the control mechanism of a machine not only that the protective mechanism is closed but also that there is present a locking force high enough to keep the protective mechanism reliably in the closed state.

If the first sensor element 31 in the actuator 3 is used for this purpose, reaching of the assignable threshold value for the locking force F may be used to determine if an exchange of signals between the first and second component sets 10, 14 between actuator 3 and read head 2 is possible.

FIG. 6 presents a diagram of a locking force F measured as a function of the distance d between actuator 3 and read head 2 in the case of a locking system 1 as illustrated in FIG. 4. The distance d was varied from 0.1 mm to 1.1 mm. The Hall voltages U_{Hall} measured with the other Hall element 39 may be correspondingly associated with an empirically determined locking force F characteristic. Correlation of measured Hall voltage U_{Hall} with locking force F depends in particular on the configuration of the other Hall element 39 relative to the electromagnet 7, on the geometry of the electromagnet 7, and on the geometry and material of the counterelement 12 on the actuator 3.

The value pair U_{Hall}/F generally determined with a prototype may be stored by means of electronic data storage in a reference table, or it may be found from the empirically determined values for the respective locking system 1. The measured values shown are based on a rated volume of the electromagnet 7. For this purpose a Hall voltage of approximately 2.87 volts was measured at a distance $d = 0.1$ mm, this corresponding to a locking force of more than 900 N. At a distance $d = 1.1$ mm a Hall voltage of approximately 2.50 volts was measured, this corresponding to a locking force of approximately 60 N.

FIG. 7 presents a diagram of a protective mechanism 47, for example, one with a protective grill 48 by which the operating area of a machine tool may be closed off, in particular to protect operating personnel and to prevent access to the machine tool during operation. The protective grill 48 may be moved in the direction of the double arrow 49. The actuator 3 secured on the protective grill 48 operates when the grill is in the closed state in conjunction with the read head 2; in particular signals are exchanged between the two component sets 10, 14. The closed state of the protective grill 48 may be determined by means of the electromagnet 7. The read head 2 is connected by way of the connecting line 51 to the evaluation unit 46, unless this unit is integrated with the read head. The evaluation unit 46 transmits signals to the control mechanism

of the machine tool over the control line 52, in particular in order to signal the closed state of the protective grill 48 and thereby indicate freeing of the machine tool for operation, and accordingly receives signals from the control mechanism, in particular for activation of the electromagnet 7 to determine the closed state of the protective grill 48 during operation of the machine tool.